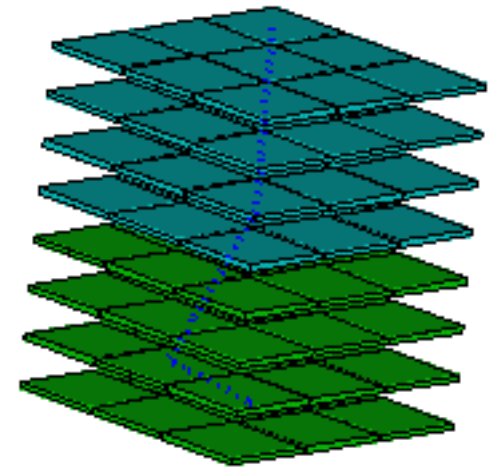
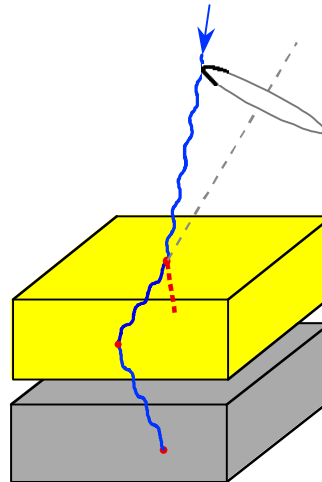
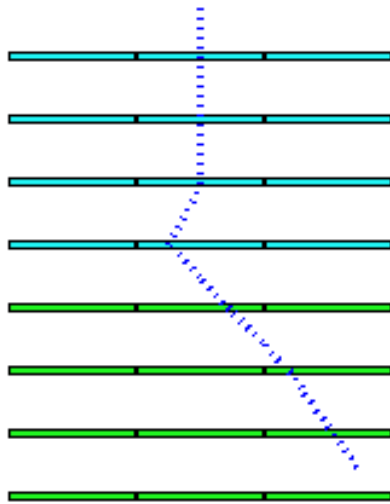


# Status of Simulations for *Advanced Compton Telescopes*

R. Marc Kippen    UAH / NSSTC



## Outline

1. *The role of simulation*
2. *Past accomplishments*
3. *Current Status*
4. *Future goals & requirements*



# The Role of Simulation

## Primary Uses

1. Early development of instrument concepts
  - ★ Primarily physical simulation studies with crude detector assumptions
2. Development and optimization of engineering systems concepts
  - ★ Physical simulation + engineering simulations
3. Demonstrate instrument + Eng. system performance
  - ★ “End-to-end” performance demonstration
4. Detailed characterization of instrument response for use in flight analysis

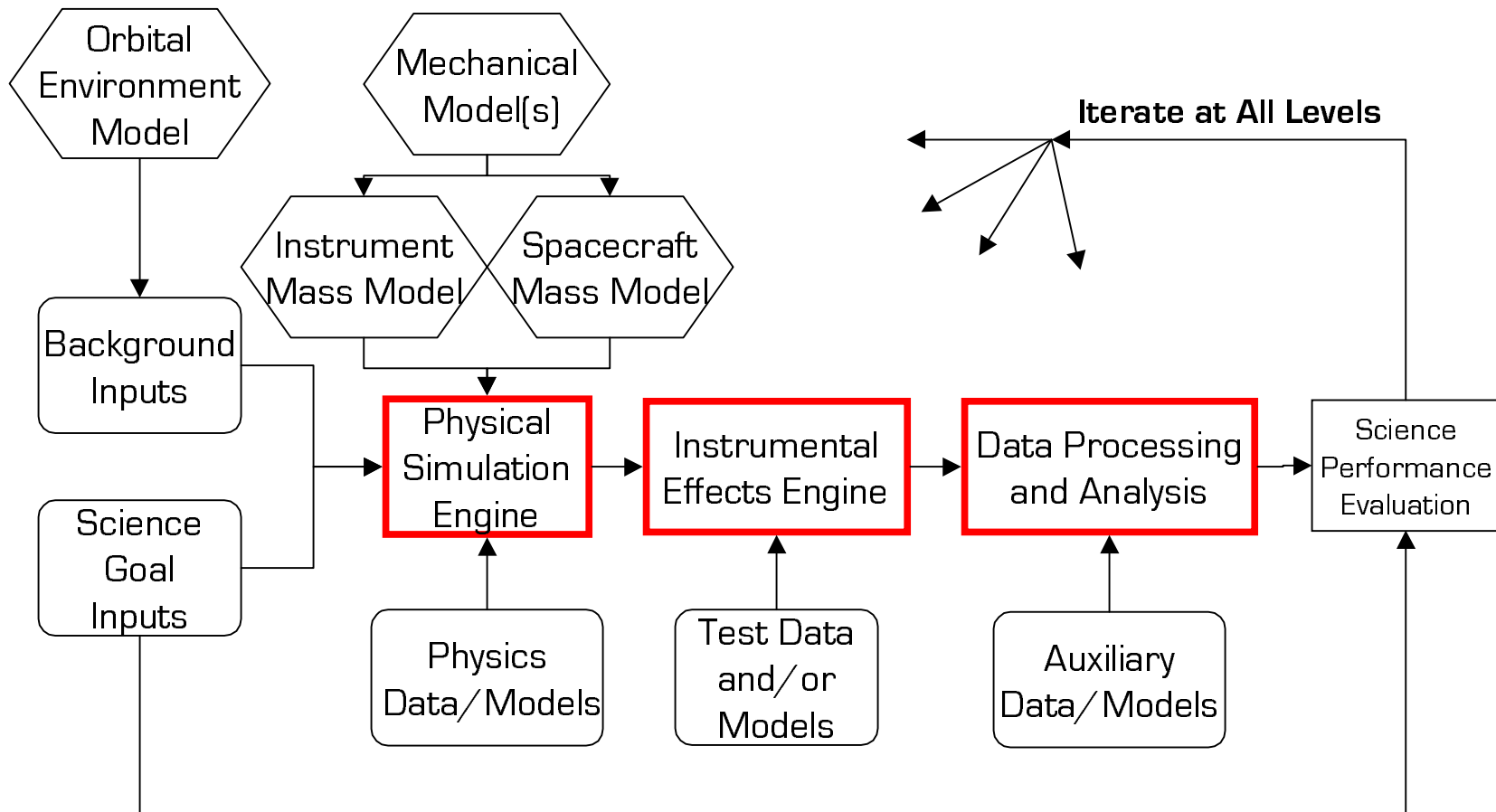
## Benefits

1. Cost-effective means for making quantitative comparisons between different concepts and configurations
2. Early identification of instrument design reduces mission technical risk
3. Early identification and verification of scientific objectives enhances mission/proposal credibility
4. Provides a crucial test-bed for the development of data processing and analysis algorithms/systems
5. Often the only viable means of evaluating detailed instrument performance for varied conditions



# Instrument Simulation Framework

**Credible Simulation Requires Credible Inputs at All Levels**





# Compton Telescope Simulation Requirements

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## ★ Physical simulation (gammas)

- ★ Need full EM physics in the  $\sim 1$  keV–50 MeV regime
- ★ Compton scattering, including Doppler broadening and polarization
- ★ Sensitive to geometry of active and passive telescope materials

## ★ Physical simulation (background)

- ★ Hadronic cascades, spallation, isotope production, radioactive decay
- ★ Time-dependent buildup & decay
- ★ Background environment models
- ★ Sensitive to geometry of active and passive telescope materials

## ★ Instrumental effects — Appl. specific

- ★ Non-ideal resolution, thresholds, noise, cross-talk, etc.
- ★ Hardware triggers, event selection, coinc/ anit-coinc, etc.

## ★ Low-level analysis (“reconstruction”)

- ★ Distinguish one or more different event types
- ★ Single Compton, multiple Compton, electron tracks, pair tracks
- ★ Kinematic event reconstruction of energy and direction (and polarization)
- ★ Background rejection techniques and data selections/cuts

## ★ High-level analysis (“imaging”)

- ★ Extremely large data space makes “binning” impractical
- ★ Instrument response difficult (or impossible) to fully characterize
- ★ Many different data types with different response characteristics

# Past Accomplishments

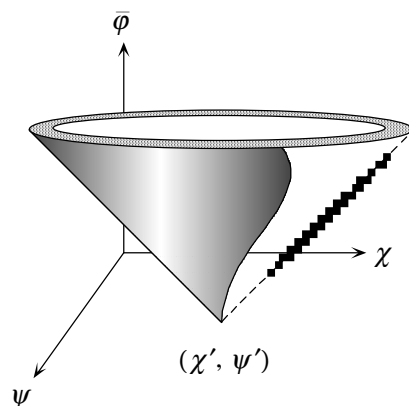
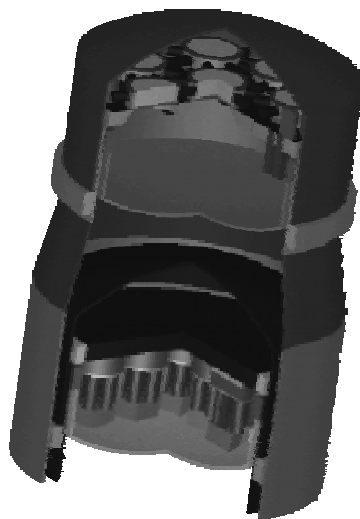
## ★ CGRO-COMPTEL (1991-2000)

### ★ Physical simulation

- ★ EM physics only
- ★ Spacecraft not included in model

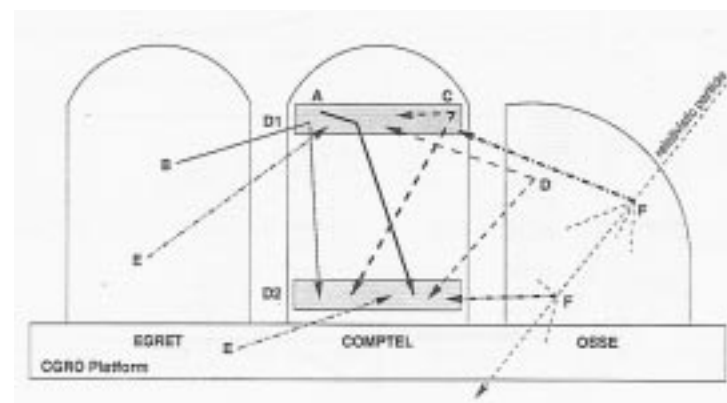
### ★ Response/Imaging

- ★ 3D binned dataspace; approximations for energy & angular dependence; deconvolution using Max. Likelihood, Max. Entropy, etc.



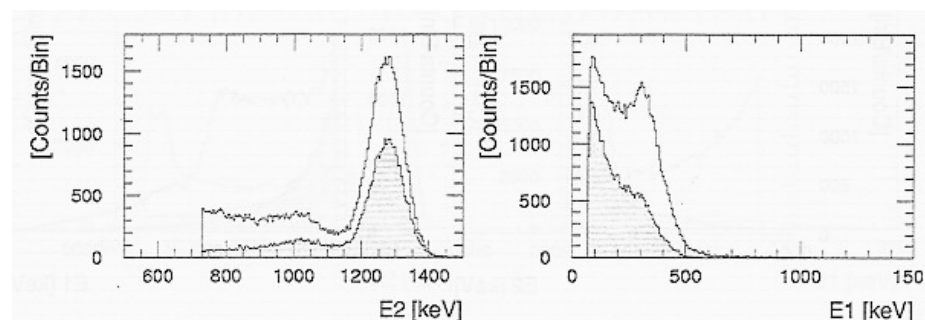
## ★ Background simulation

- ★ Identify candidate sources (lines)
- ★ Simulate particular sources
- ★ Empirical fit to data + growth curves



Weidenspinner 1999

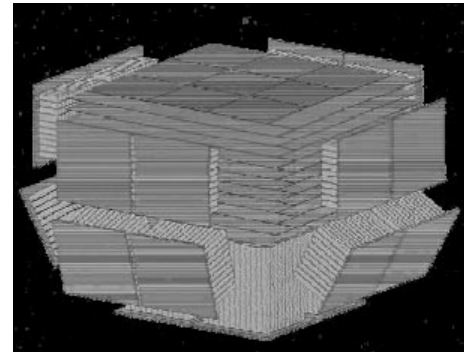
$^{22}\text{Na}$  simulation (two-photon decay of Al)



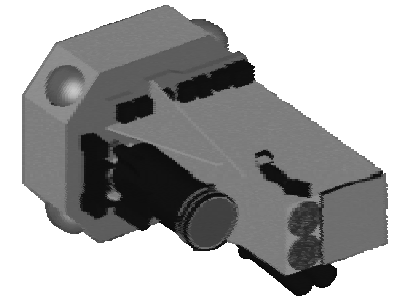


## Current Status – Simulation Efforts

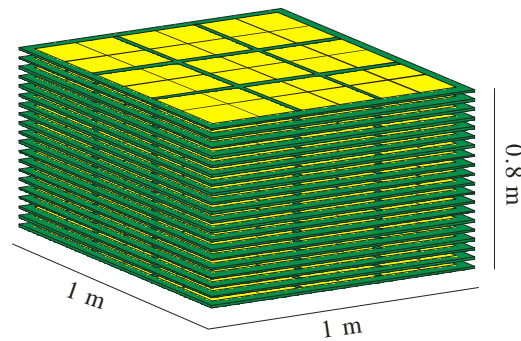
- ★ Improved EM physics (Doppler broadening, polarization)
- ★ Kinematic reconstruction of multiple Compton scatter events
- ★ Electron and pair tracking
- ★ Background simulation efforts
- ★ Image deconvolution efforts



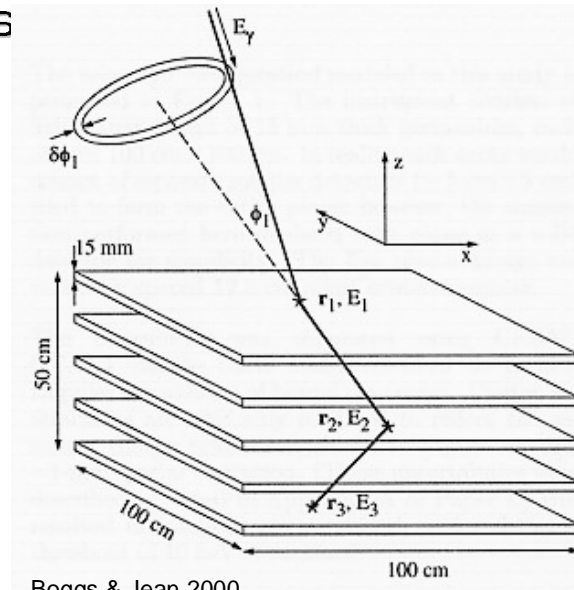
MPE group 2000



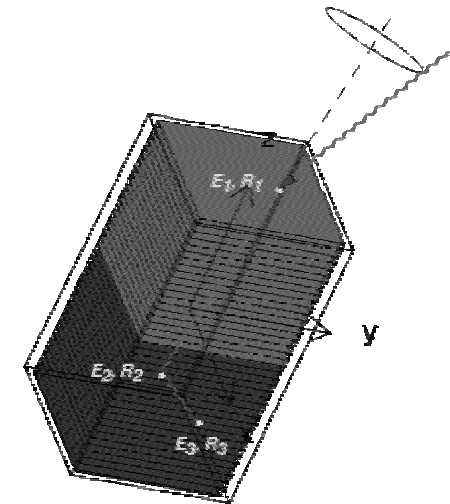
Southampton group 2000



NRL group 2000



Boggs & Jean 2000

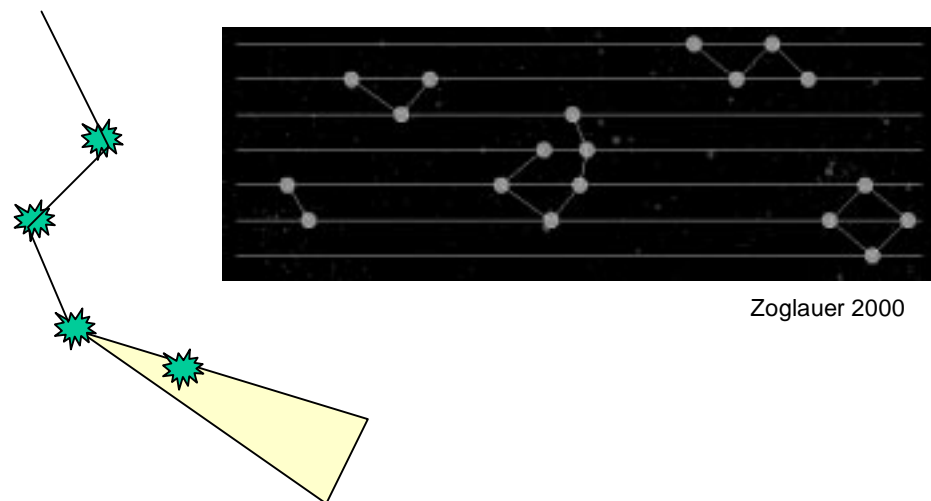
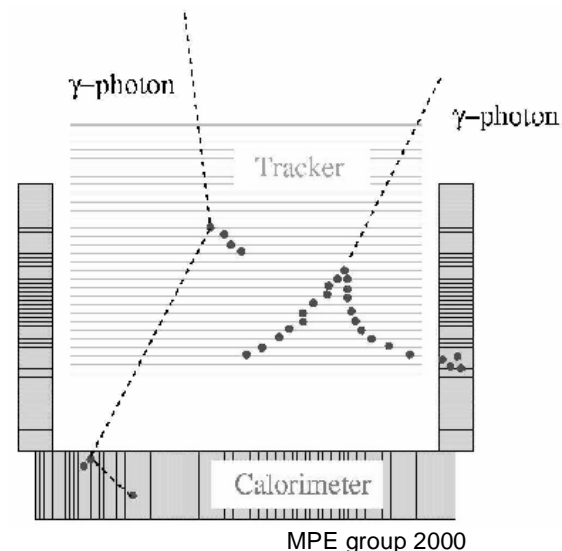


UAH group 2000



## Current Status — Reconstruction Algorithms

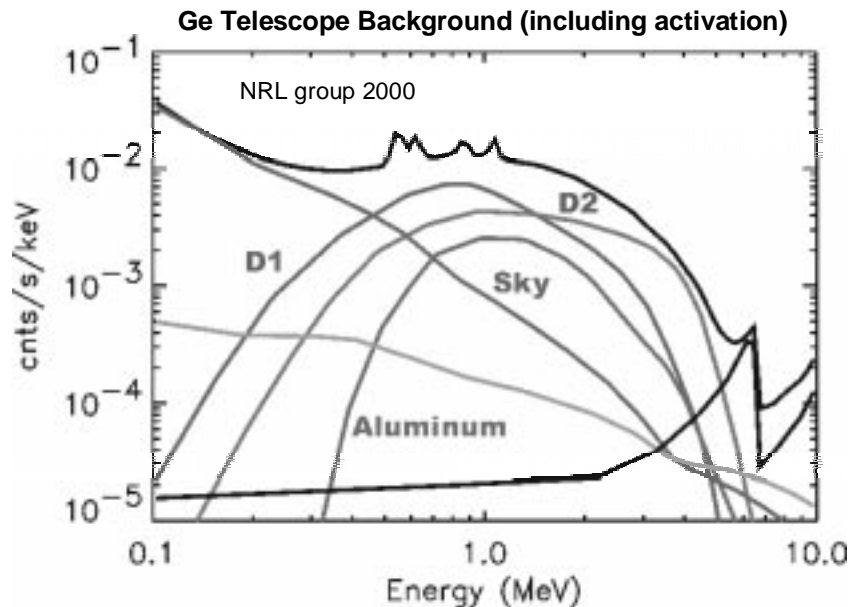
- ★ Multi-Compton technique — total energy deposition (e.g., Kamae et al.; Aprile et al.)
  - ★ 3-Compton technique — partial energy deposition (NRL)
  - ★ Electron tracking (UCR & MPE)
  - ★ Pair tracking (UCR & MPE)
- 
- ★ Difficulties:
    - ★ Optimized sequence identification
    - ★ Doppler broadening at low-E
    - ★ Distinguishing Compton events from electron tracks
    - ★ Application-specific “expert systems” approach; no general treatments



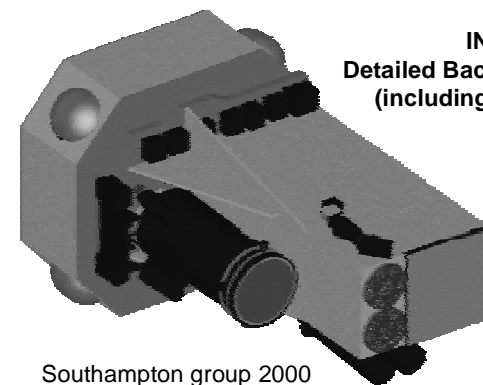
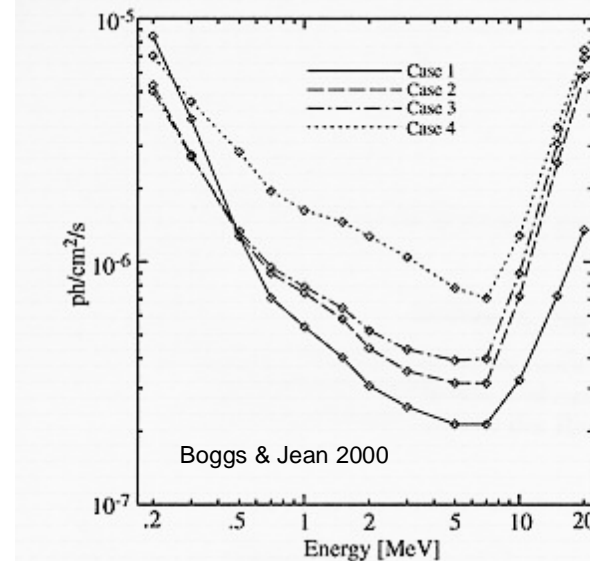


## Current Status – Background Simulations

- ★ Background simulations lag behind gamma simulations
- ★ Many empirical estimates, scaling from balloon flights & COMPTEL
- ★ Few detailed (hadronic+decay) cases, typically with simple mass models



**Ge Telescope Line Sensitivity (including activation)**



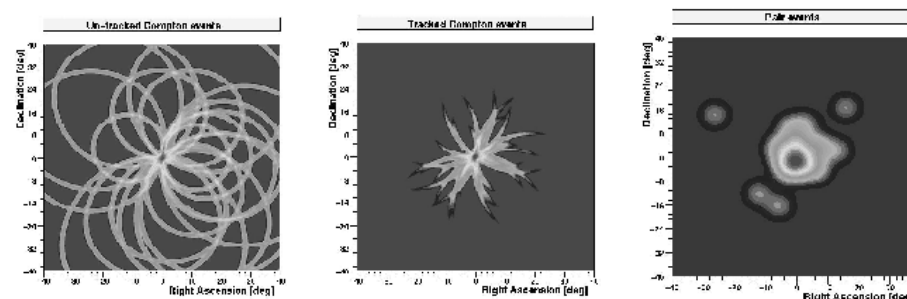
**INTEGRAL**  
Detailed Background Simulation  
(including Compton mode)

Southampton group 2000



## ★ General problems

- ★ fine position and energy resolution result in too many pixels to handle in a binned dataspace
- ★ Many different event types with unique response properties
- ★ Back-projection loses information

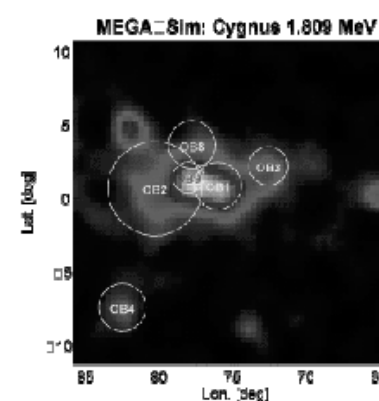
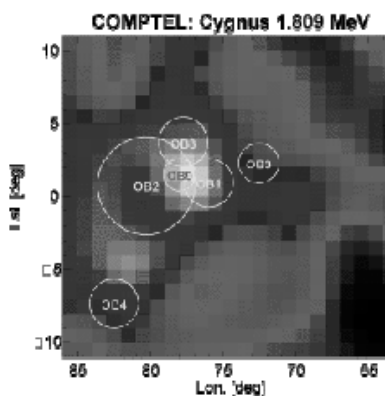
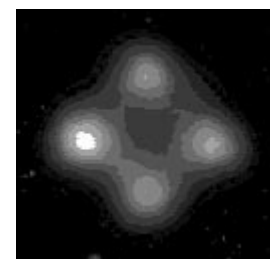


## ★ Potential solution

- ★ List mode imaging where each photon carries the dataspace
- ★ Maximum Likelihood Expectation Maximization (e.g., Barrett et al. 1997; Wilderman et al. 1998; Zoglauer 1999)

## ★ Drawbacks

- ★ Requires knowledge of response and background for each photon



Zoglauer et al. 2000



# Summary of Future Needs

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## ★ Simulation framework

- ★ Unified framework incorporating science inputs, physical simulation, instrumental effects & analysis not practical given current funding
- ★ Unification of some aspects is needed

## ★ Physical simulation

- ★ Currently using several different MC packages (EGS, GEANT, MCNP)
- ★ Single Monte Carlo package to handle all requisite source & background physics is in sight: GEANT4
- ★ Mass model CAD translation tools are sorely lacking
- ★ Input background models in some areas need to be refined
- ★ Techniques for handling “rare” background lines are needed

## ★ Event reconstruction

- ★ More work on general methods for reconstruction of arbitrary event types (neural nets, data fusion; AI ?)
- ★ More work on polarization
- ★ Electron tracking: take advantage of GLAST work?
- ★ More work on algorithms to reduce background

## ★ Imaging

- ★ Current ML-EM does not handle background
- ★ More work on adapting traditional likelihood methods
- ★ Simplified response representations



## Simulations Breakout Discussion

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★ 1:30 – 3:30

★ Suggested topics:

- ★ Simulation group status reports
- ★ GEANT4 status
- ★ Radioactive decay module
- ★ Geometry & CAD interfaces
  
- ★ Event reconstruction status reports and discussion
  
- ★ Imaging status reports and discussion
  
- ★ Summarize for panel discussion



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